Linking Type IIn Supernovae with Massive Progenitors

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Background

Type IIn supernovae, also called interacting SNe, are surrounded by dense circumstellar material (CSM) caused by progenitor mass loss episodes prior to explosion. The spectra of this subcategory are characterized by strong, narrow emission lines, the profiles of which contain information about the density, temperature, and geometrical configuration of the CSM and, by extension, the progenitor's mass loss. Thus, studying the characteristics of the CSM can help pinpoint candidate stellar progenitors of SNe IIn. As a first step in this process, we analyze the shape of the Hα line in the Type IIn SN 1997eg (see Figure 1) by comparing it with a set of artificially generated ones.

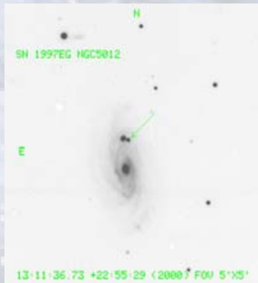

Figure 1: Image of SN 1997eg and host galaxy. http://www.cfa.harvard.edu/supernova/images/sn97eg.gif

Introduction and Methods

The prominence of Hα makes it an ideal candidate for probing the properties of the CSM. Because the CSM is composed largely of hydrogen heated and ionized by the supernova, the H alpha line profile is the result of a complex set of radiative processes. Computational methods enable us to simulate these processes and construct model line profiles. Data for this supernova were obtained using the Low-Resolution Imaging Spectrometer at the Keck II 10 m telescope, 44 days post discovery.

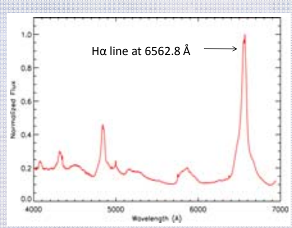

Figure 2: Spectrum of SN1997eg taken at Keck (Hoffman et al. 2008, ApJ, 688, 1186).

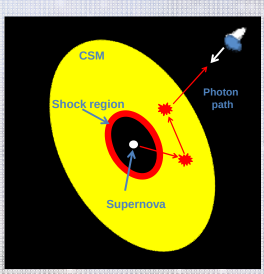

Figure 3: Path of a photon through the *SLIP* code

SLIP (Supernova LIne Polarization) is a 3-dimensional radiative transfer code that tracks photons as they scatter through model CSM configurations (see Figure 3). In the code, photons originate from a central supernova "source", a warm stationary CSM configuration composed of partly ionized hydrogen, and a fully ionized "shock" region interior to the CSM. In addition to being a source of photons, the CSM also both scatters and absorbs photons. *SLIP* tracks photons as they move through the system and records their outgoing directions when they exit to create spectra at each viewing angle.

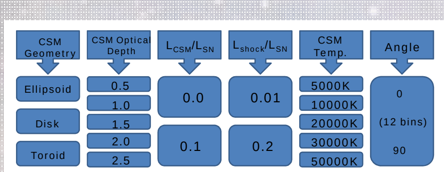

Figure 4: Current parameter space for the model grid spans 6 dimensions and contains 3000 unique spectra.

We used *SLIP* to create model spectra between 6000 Å and 7000 Å. Different combinations of parameters resulted in a grid of 300 models seen from 12 different viewing angles. Figure 4 illustrates the 6 dimensional parameter space of our model grid. An inclination value of 0 indicates a "face-on" viewing angle, while 90 indicates "edge-on." Geometries are simple configurations often seen in stellar winds and outflows. Temperatures and optical depths were chosen to span a range of values given typical conditions in circumstellar material surrounding hot stars. CSM and shock luminosities are fiducial values whose variation we have not fully investigated.

We used a χ^2 analysis to compare our models with the observed data and identify a best fit. We developed IDL routines to cycle through all model parameters and viewing angles, to calculate the χ^2 value describing the "goodness of fit" between each model and the SN 1997eg data, and to visualize how the χ^2 values varied over the parameter space.

Acknowledgments

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SN data courtesy A. Filippenko, UC Berkeley.
Background Image (Pelican Nebula): http://www.ccdcam-astrophotography.net/fsq106ed/index.html

Results

Model Grid

In Figures 5 through 7, we display the variation of χ^2 values with various model parameters for toroidal CSM geometries. The location of our current best fit is marked with a red star in each figure. Figure 5 shows that for this set of models, the lowest χ^2 values occur at a range of Temperatures, but tend to favor more edge-on viewing angles. As seen in Figure 6, the current minimum χ^2 occurs at the highest optical depth we tested. Running additional models at higher optical depths could improve the fit for this particular spectrum.

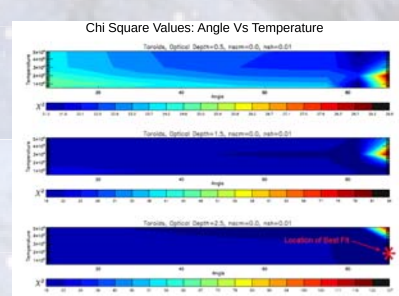

Figure 5: The progression of χ^2 values as a function of temperature and viewing angle for three different optical depths.

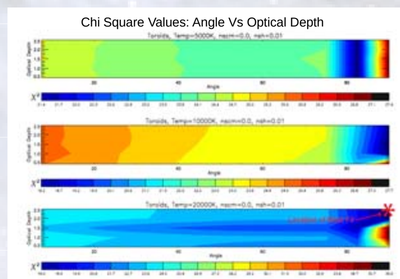

Figure 6: The progression of χ^2 values as a function of optical depth and viewing angle for three different temperatures.

Interestingly, we see very little variation in χ^2 with viewing angle for some temperatures and optical depths, while for others the variation is much stronger. The first three panels of Figure 7 show viewing angles for which low χ^2 values are well constrained (our current best fit, however, occurs at a fourth, fully edge-on, viewing angle). This suggests that in cases where CSM characteristics are well known from prior analysis, line profile fitting with *SLIP* can be used to determine the viewing angle about a toroidal CSM configuration.

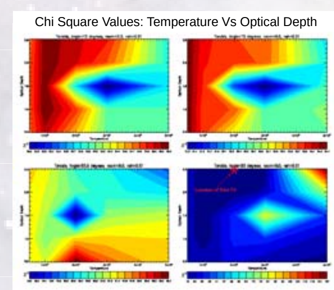

Figure 7: The progression of χ^2 values as a function of temperature and optical depth for four different viewing angles.

Best Fit

We identified the minimum χ^2 value for all 3600 model spectra, belonging to a toroid viewed at 90 degrees (edge-on) with the following characteristics: optical depth of 2.5, and temperature of 20,000 K, with 1% of photons originating from the shock region and none from the CSM. This best fit model is consistent with the scenario proposed by Hoffman et al. (2008, ApJ, 688, 1186), who analyzed spectral and spectropolarimetric observations of SN 1997eg and suggested that the CSM distribution included a dense equatorial region viewed nearly edge-on.

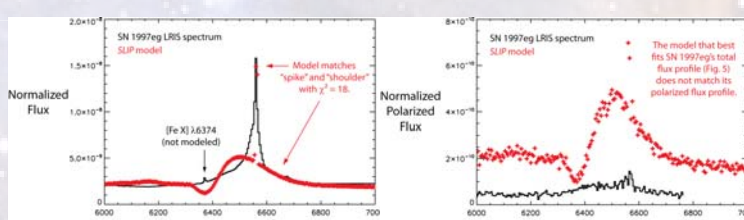

Figure 8: Best fit model data is shown in red superimposed over observational data from SN 1997eg. The left panel shows normalized flux as a function of wavelength, while the right shows polarized flux.

As Figure 8 shows, our best-fit model provides a good match to the height of the narrow "spike" and the slope of the red "shoulder" in the Hα line of SN 1997eg at day 44. However, the same model does not match the line profile in polarized light (right panel). In the next part of the project, we will fit flux and polarized flux profiles simultaneously to further constrain the scattering characteristics of the CSM. Our method of line profile fitting with *SLIP* shows promise as a diagnostic tool for the properties of the CSM around interacting SNe, which can lead to more robust links with progenitors and their winds.

Future Work

The current model grid can be improved by increasing optical depth to constrain the best fit in that direction. We are also currently analyzing the χ^2 values of the disk and ellipsoid models to see how these overall trends depend upon geometry. The grid shows some degeneracy in the generated line profiles; that is, unique combinations of parameters do not lead to unique line profiles. Our current analysis of the CSM surrounding SN 1997eg will be improved after we complete a similar model comparison using the polarized data. We also plan to expand the model analysis to include more epochs of data, different spectral lines, and spectra of other type IIn supernovae.

SLIP does not currently account for more complex behavior such as the expansion of the ejecta or the CSM. We plan to augment the code to include these other phenomena.